

ROSAT PSPC spectra of X–ray selected Narrow Emission Line Galaxies

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ABSTRACT

We analyse the ROSAT PSPC spectrum of 19 X–ray selected Narrow Emission Line Galaxies (NELGs) discovered during the optical identification of sources in the ROSAT UK Deep Survey. Their properties are compared to those of broad line Active Galactic Nuclei (AGN) in the same sample.

Counts in three spectral bands have been extracted for all the sources, and have been fitted with a power-law model assuming the Galactic value for N_H . The average slope of NELGs is $\alpha = 0.45 \pm 0.09$, whilst for the AGN it is $\alpha = 0.96 \pm 0.03$. The power-law model is a good fit for $\sim 90\%$ of NELGs and $\sim 75\%$ of AGN.

Recent work shows that the fractional surface density of NELGs increases with respect to AGN at faint fluxes. Thus they are expected to be an important component of the residual soft (< 2 keV) X–ray background. The slope of the X–ray background ($\alpha \sim 0.4$, 1–10 keV) is harder than that of AGN ($\alpha \sim 1$) but our results show that it is consistent with the summed spectrum of the NELGs in the deep survey ($\alpha \sim 0.4$). This may finally reconcile the spectrum of the background with the properties of the sources that constitute it.

Key words: X–ray background, emission line galaxies.

1 INTRODUCTION

The soft (< 2 keV) X-ray background is thought to arise from the integrated signal of individual unresolved sources (Fabian and Barcons, 1992, and references therein). Although broad line AGN are known to be the main contributors to the soft X-ray background at higher fluxes (Shanks et al. 1991; Boyle et al. 1994), their spectral shape (energy index, $\alpha \sim 1$, Maccacaro et al. 1988) seems too steep to match that of the background ($\alpha \sim 0.4$, 1-10 keV, Gendreau et al. 1995, Chen et al. 1996). Hence a new population of harder and fainter sources, with a steep Log N-Log S and which do not contribute significantly above fluxes $\sim 10^{-14}$ erg cm $^{-2}$ s $^{-1}$, has been sought in order to resolve this spectral paradox (Hasinger et al. 1993). Narrow Emission Line Galaxies (NELGs) seem to be an attractive candidate for this new contributor to the X-ray background at fainter fluxes (Jones et al. 1995a, Boyle et al. 1995).

NELGs are generally defined as galaxies which possess only emission lines with FWHM < 1000 km s $^{-1}$ in their optical spectra. They can be substantially brighter than normal galaxies in X-rays. Thus for example Fabbiano (1989) finds X-ray luminosities in the range $\sim 10^{38} - 10^{42}$ erg s $^{-1}$ (0.2 - 3.5 keV) for normal galaxies, while our sample of NELGs yields $\sim 10^{41} - 2 \times 10^{43}$ erg s $^{-1}$ when extrapolated to the same energy band. The number ratio of NELGs has recently been found to increase at faint X-ray fluxes (Jones et al. 1995a, Boyle et al. 1995), leading to the suggestion that they may be important contributors to the unresolved fraction of the X-ray background. However, in order to solve the soft X-ray spectral paradox, NELGs would need to have a flatter spectrum than the X-ray background, to compensate for the steeper slope of AGN.

In this paper we examine X-ray data on faint NELGs to determine if their integrated spectrum can reproduce the spectral shape of the X-ray background. We present a total sample of 19 NELG from the UK Deep Survey, and compare their spectra to that of broad line AGN from the same survey, and to the spectrum of the soft X-ray background. In section 2, the deep survey sample is described. In section 3 we explain the data reduction and analysis process. We report and discuss our results in section 4, and in section 5 we present our conclusions. A preliminary report of this work was given in Romero-Colmenero et al. (1996).

Table 1. Spectral results on Deep Survey NELGs

ID	extraction	z	α	Hard Counts ^a	Fx (0.5-2 keV)	Lx (0.5-2 keV)
Number	radius (arcsec)			PHA channels 52-201	10^{-14} erg cm ⁻² s ⁻¹	10^{40} erg s ⁻¹
032	43	0.068	-2.41 ± 0.40	101.98 ± 13.03	1.96 ± 0.43	34 ± 7
036	41	0.235	0.18 ± 0.26	89.68 ± 11.49	1.31 ± 0.20	328 ± 49
042	18	0.366	-0.15 ± 0.88	50.71 ± 9.78	0.76 ± 0.22	430 ± 116
043	25	0.382	0.81 ± 0.25	69.76 ± 13.32	0.99 ± 0.20	827 ± 167
047	18	0.364	0.49 ± 0.56	36.48 ± 8.79	0.52 ± 0.15	357 ± 101
051	54	0.062	0.78 ± 0.19	64.77 ± 10.56	0.92 ± 0.16	16 ± 3
060	26	0.580	0.51 ± 0.37	38.47 ± 7.60	0.55 ± 0.12	1062 ± 237
067	54	0.554	-1.85 ± 1.77	44.71 ± 9.50	0.81 ± 0.38	497 ± 234
085	48	0.304	-0.29 ± 1.35	19.89 ± 7.50	0.30 ± 0.17	113 ± 64
093	49	0.590	0.57 ± 0.47	36.88 ± 8.81	0.53 ± 0.14	1085 ± 295
094	54	0.061	-0.41 ± 1.38	24.88 ± 8.48	0.39 ± 0.21	6 ± 3
103	32	0.200	1.31 ± 0.32	34.03 ± 9.81	0.48 ± 0.14	100 ± 30
117	54	0.064	-0.33 ± 1.86	13.00 ± 7.67	0.22 ± 0.18	4 ± 3
121	27	0.310	-0.13 ± 0.93	27.10 ± 7.06	0.41 ± 0.15	166 ± 61
127	23	0.250	0.88 ± 0.48	22.07 ± 6.40	0.31 ± 0.10	103 ± 33
131	24	0.576	0.87 ± 0.54	22.87 ± 7.21	0.32 ± 0.11	720 ± 246
132	28	0.223	1.63 ± 0.26	19.18 ± 5.77	0.25 ± 0.08	74 ± 24
134	49	0.250	0.38 ± 0.83	26.33 ± 8.09	0.38 ± 0.15	113 ± 43
135	32	0.520	0.93 ± 0.58	17.15 ± 6.46	0.24 ± 0.10	423 ± 172

^a Corrected for PSF and vignetting. The error is the uncertainty in the counts.

Note: All errors quoted in the table are 1 σ deviation.

2 THE SAMPLE

The UK Deep Survey (Branduardi-Raymont et al. 1994, McHardy et al. 1996) involves an optical identification programme of a deep (>105 ks exposure) ROSAT PSPC pointed observation. It covers 0.2 deg² of sky in an area where the Galactic N_H is low ($\sim 6.5 \times 10^{19}$ cm⁻²) and relatively uniform (Jones et al. 1995b). The survey reaches a flux limit of 2×10^{-15} erg cm⁻² s⁻¹ (0.5-2 keV). Only sources with offaxis angle up to 15 arcminutes have been used due to the larger positional uncertainty and possible masking by the detector window support structure at larger radii. Source searching was carried out in the energy range 0.5 to 2.0 keV (PHA channels 50 - 200), as the softer band has a larger point spread function (PSF), higher diffuse Galactic X-ray emission and a larger contribution of Galactic stars, which complicate the detection of extragalactic sources.

Low resolution (10 - 15 Å) optical spectra were obtained on the Nordic Optical Telescope (NOT), the University of Hawaii 88 in Telescope, the Multiple Object Spectrograph (MOS)

on the Canada-France-Hawaii Telescope (CFHT) and the ISIS spectrograph on the William Herschel (WHT) Telescope (McHardy et al. 1996).

About 90% of the X-ray sources have been identified and 19 NELGs and 33 AGN are contained in the sample. The NELGs may consist of a mixture of starburst, LINER and Seyfert 2 galaxies, though the precise classification within this group remains uncertain in many cases.

3 X-RAY SPECTRAL ANALYSIS

As most of the UK Deep Survey sources are too faint to warrant construction of full resolution spectra, we have measured X-ray counts in three bands and applied a fitting procedure developed by Mittaz et al. (1996) to determine the spectral parameters of the sources. The procedure uses a maximum likelihood technique based on the poissonian distribution of counts (Cash, 1979) to fit a spectral model together with an accurate background estimate to the observed source plus background counts. By using the total number of observed counts (source plus background), the poissonian nature of the data is correctly described. This technique is used in preference to the χ^2 statistic which assumes a gaussian probability distribution of the counts; the difference can become important for low source counts such as those in our sample. The spectral fitting procedure has been checked on bright sources taken from the ROSAT International X-ray Optical Survey (RIXOS). Excellent agreement is found between the results of the three-band fits to the data and those obtained using the software package XSPEC applied to data with the full PHA resolution of the PSPC (Mittaz et al. 1996).

The three spectral bands used in this analysis are defined as: S (PHA channels 8 – 41 inclusive), H1 (channels 52 – 90) and H2 (channels 91 – 201). At the first stage in the reduction process, we excluded intervals of high master veto rate and bad aspect solution, and also intervals of anomalously high and low count rate in the time series of the whole field, leaving 85 ks of ‘clean’ data. The source counts are obtained using the software package ASTERIX, summing all the counts in each band from a circle centred at the source position. The radius of the extraction circle was nominally 54 arcseconds. However where the extraction circles of two sources overlap, this radius was reduced to one half of the distance between the source and its nearest neighbour. The resulting counts were corrected for the ‘missing’ fraction of the PSF response using the data of Hasinger et al. (1994). A large,

annular (4.8 - 10.2 arcminutes radii) region centred on the pointing position of the field, was used to calculate the average background in each band with the sources masked out, after correcting for vignetting using the exposure map provided with the original data.

A two parameter (α , Normalization) power-law model with the neutral hydrogen absorbing column (N_H) fixed to the Galactic value ($6.5 \times 10^{19} \text{ cm}^{-2}$) was used in the fitting process, leaving one degree of freedom. The detector response function, the background level and corrections for vignetting and energy dependent PSF effects were folded into the fitting process.

4 RESULTS AND DISCUSSION

Table 1 lists the results of the power-law fits to the data on the 19 individual NELGs in our sample. As noted previously, the absorption was fixed at the Galactic value. The fluxes were obtained from the source counts, using the ROSAT PSPC response matrix, and correcting for the Galactic N_H . We have adopted a value of $q_0 = 0$ and $H_0 = 50 \text{ km sec}^{-1} \text{ Mpc}^{-1}$ when calculating the X-ray luminosities.

The single power-law model with N_H fixed to the Galactic value is an adequate fit to most of the sources. However, based on the residuals to the fit, there is evidence for a somewhat higher absorbing column and a steeper slope in $\sim 10\%$ of the NELGs and $\sim 25\%$ of the AGN. There is no evidence for a systematic trend of NELG spectral slope with, say, luminosity or redshift (Table 1).

The slope for each individual NELG and AGN in the sample has been plotted against the total signal in PHA channels 52-201 in Fig 1. The number distribution of the two source types is shown in Fig. 2. From these figures it can be seen that the brighter sources are AGN, whilst NELGs only appear and become important in the faint end of the distribution, below ~ 120 counts. Even though there is a significant dispersion of slopes from source to source, there is an indication even in these data that the slope of the NELGs is systematically harder than that of the AGN.

To investigate further the difference between the X-ray spectra of NELGs and those of broad line AGN, we co-added the NELG and the AGN counts in each band and created an average spectrum of these two types of sources, taking into account the different offaxis angle of each source and correcting for the vignetting effect. By summing the spectrum of many NELGs and AGN we are averaging the effects of dispersion in the properties of in-

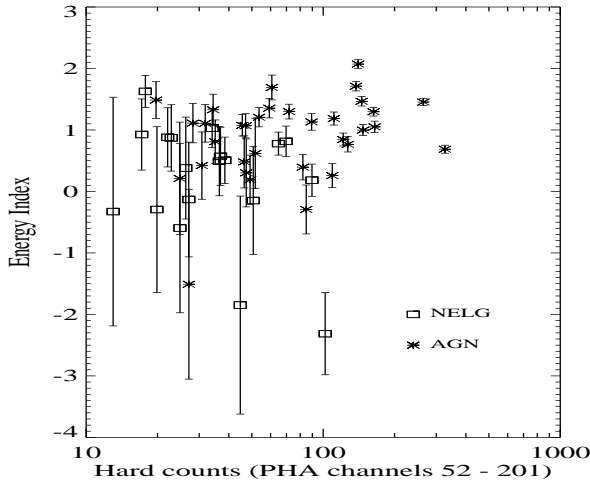


Figure 1. Energy index versus counts in PHA channels 52 - 201 for AGN and NELGs in the UK Deep Survey.

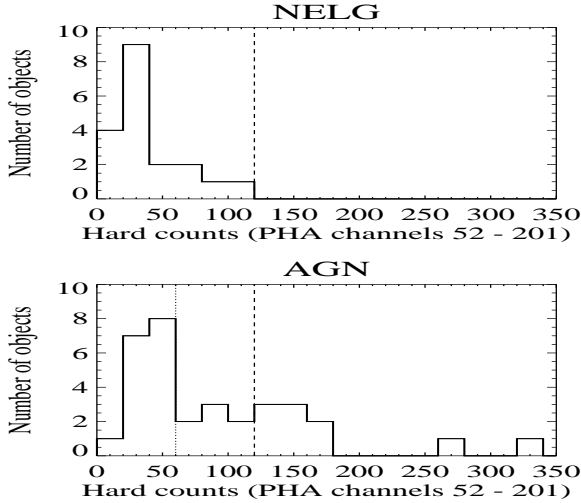


Figure 2. Number of sources versus counts in PHA channels 52 - 201

dividual objects, mimicking the way the unresolved X-ray background is measured. These average spectra were then fitted in the same way as the individual sources. A probability distribution for the power-law slope is obtained by projecting (integrating) the two dimensional maximum likelihood surface in normalisation and slope along the normalisation axis to define probability densities for the spectral slopes (Cash 1979).

To ensure that there is no bias in the spectrum as a function of count rate (such as might be introduced by imperfect background subtraction for example) we have used only AGN with <120 counts in order to match the count range of the NELG sample. This leaves 23 AGN in the sample. The probability distribution for the AGN and NELGs energy indices

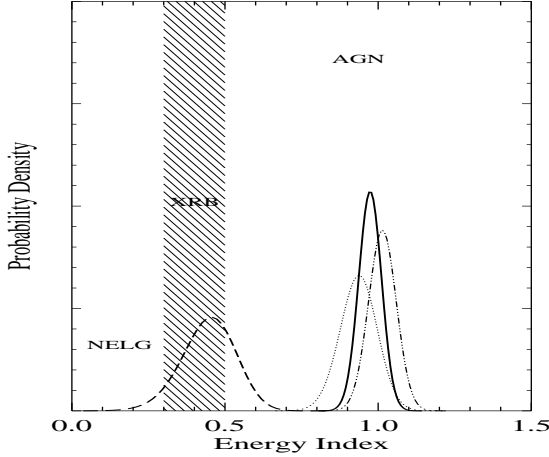


Figure 3. Probability distribution of AGN and NELG spectral slopes. The shaded area represents the X-ray background slope, the width of which reflects its uncertainty (Gendreau et al. 1995). The dashed line represents the NELGs distribution. The solid line is used for AGN with less than 120 counts in the PHA channels 52 - 201. These AGN have been further divided into two subsamples, the dotted line being used for AGN with less than 60 counts, and the dash-dotted line representing AGN with counts between 60 and 120. See text for details.

are compared in Fig. 3. We find that the mean slope of the AGN is $\alpha = 0.96 \pm 0.03$ (1-sigma) while that of the NELGs is $\alpha = 0.45 \pm 0.09$.

The error quoted for the mean slope of the AGN and NELG samples is statistical only, which is appropriate because we are interested in their relative value and systematic errors would affect both samples in the same way. However, systematic errors will be relevant when comparing our results with those of other samples. The dominant cause of possible systematic error in our spectral extraction procedure is likely to be the background value used. To assess this we have artificially distorted the background spectral shape and refit the average source data. For illustration, if we perturb the counts in the softest and hardest channels by plus and minus 5% respectively, the slope of both the mean AGN and NELG samples changes by 0.2. We regard this as an upper limit to the size of possible systematic effects.

Given that systematic errors in the background will affect the results on faint sources more than bright sources, we have verified that the AGN and NELG populations have different mean slopes by further dividing the AGN sample into two groups which have <60 counts and counts between 60 and 120 respectively. Probability distributions for these two subsamples are also indicated in Fig. 3. Both AGN subsamples are significantly softer than the NELGs. Moreover the mean slope found for the AGN is consistent with brighter X-ray

AGN samples selected in the soft X-ray band above ~ 0.3 keV (Maccacaro et al. 1988, $\bar{\alpha} = 0.95 \pm 0.05$; Mittaz et al. 1996, $\bar{\alpha} = 1.05 \pm 0.07$).

We have excluded the ten brightest AGN in our sample from the analysis. If we include them, the mean AGN slope increases to 1.21 ± 0.01 , increasing the discrepancy with the NELG results. However it can be seen from Fig. 1 that this softening of the mean is primarily caused by 2 of these bright AGN that have a softer than average spectrum and dominate the counts.

We also note that there are inevitable selection effects in a count-rate limited sample derived with ROSAT caused by the restricted energy response of the detector. We expect the mean spectrum of source samples to be biased to softer slopes than would be the case for a flux limited sample selected over a more extended energy range and with a flatter high energy response. This should be borne in mind when comparing our results with the spectrum of the X-ray background measured, say, with ASCA which should include significant numbers of faint AGN as well as NELGs. Nevertheless, since such selection effects would affect both the AGN and NELG samples, the *difference* in the mean spectrum of the two samples seems secure.

We also note that direct measurements of the X-ray background with ROSAT may suggest a somewhat softer slope than determined with ASCA (e.g. 0.7 ± 0.3 , Branduardi-Raymont et al. 1994; 0.6 ± 0.3 , Chen et al. 1994). However the uncertainties are relatively large given the restricted energy range of ROSAT, and there are possible systematic biases due to the uncertain contribution of Galactic background emission in this band.

5 CONCLUSION

We have integrated the X-ray spectrum of 19 NELGs taken from the UK Deep Survey and compared this with the spectrum of 23 AGN of similar count rate in the same sample. We find that the NELG spectrum is harder than that of the AGN at more than 3σ confidence.

Moreover, the mean spectral slope of the NELGs ($\alpha = 0.45 \pm 0.09$) is consistent with the slope of the X-ray background between 1 and 10 keV ($\alpha = 0.4 \pm 0.1$; Gendreau et al. 1995) whereas the slope of the AGN at similar count rates is not ($\alpha \sim 1.0$).

This work is important for understanding the origin of the soft (< 2 keV) X-ray background. Extrapolation of the source number counts suggests that NELGs are the dominant source population at fluxes four times fainter than the deep survey flux limit (i.e. at fluxes

of $\sim 5 \times 10^{-16}$ erg cm $^{-2}$ s $^{-1}$ in the 0.5-2 keV band; Jones et al. 1995a, McHardy et al. 1996). The increasing number of these sources at low fluxes and their spectral properties as shown in this paper, taken together, can reproduce both the flux and spectrum of the X-ray background. This result adds considerable weight to the idea that NELGs are the major contributor to the residual unresolved soft X-ray background.

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